ECE 60022: Wireless Communication Networks
Project 1: Opportunistic Scheduling in Wireless Systems

Project Overview

In wireless communication, radio propagation depends on three basic mechanisms: reflection, diffraction, and scattering.

- Reflection occurs when a propagating electromagnetic wave impinges upon an object that has very large dimensions compared to the wavelength of the propagating wave. It occurs from the surface of the earth, buildings, walls, etc.

- Diffraction occurs when the radio path between the transmitter and the receiver is obstructed by a surface that has sharp irregularities (edges). The secondary waves resulting from the obstructing surface are present throughout the space and even behind the obstacle, giving rise to a bending of waves around the obstacle (even when a line of sight path does not exist between the transmitter and the receiver).

- Scattering occurs when the medium through which the electromagnetic wave travels consists of objects that are small compared to the wavelength and where the number of obstacles per unit volume is large. Hence, scattered waves are produced by rough surfaces, small objectives, or other irregularities in the channel.

Due to these three factors combined with the mobility of users, radio propagation (i.e., path loss) in wireless systems is *time-varying and location-dependent*, and it is quite difficult to model it in detail. Hence, in general, a simplified path loss model that incorporates the power falloff with distance, slow fading, and multipath fading is used and it is defined as:

$$P_R = Km10^{X/10} g(d) P_T, \tag{1}$$

where
P_R: received power level,
P_T: transmitted power level,
K: a constant,
d: distance between the transmitter and the receiver,
$g(d)$: power falloff with distance,
$10^{X/10}$: slow fading,
m: multipath fading.

The average received power level decreases with distance, and it is expressed as a function of distance by using a path loss exponent. Hence, $g(d)$ in Eq. (1) can be represented by

$$g(d) = \frac{k}{d^{\alpha}},$$

where k is a constant and α is a path loss exponent. Slow fading is, in general, caused by variations in radio signal power when the signal encounters terrain obstructions such as hills or man-made obstructions such as buildings. It results in medium-scale fluctuation around the average power and occurs over distances of tens to hundreds of meters (typically much larger than a wavelength). Empirical evidence and theoretical analysis suggest that the received power fluctuates about the average power according to a log-normal distribution. Hence, X in Eq. (1) can be represented as a random variable with a zero-mean normal distribution. Multipath fading is used to describe the rapid fluctuation of the amplitude of a radio signal over a short period of time or travel distance. It is caused by interference between two or more versions of the transmitted signal that arrive at the receiver at slightly different times. The multipath fading component m in Eq. (1) can be represented as a random variable with either a Rayleigh distribution or a Ricean distribution.

Due to time-varying slow and multipath fadings, path loss is also time-varying. Furthermore, the received interference at a user due to other transmission and background noise is also constantly varying. All these contribute to the time-varying channel condition of a user in wireless systems. In general, the channel condition of a user can be measured by the Signal to Interference and Noise Ratio (SINR), which is defined by

$$SINR = \frac{\text{desired signal power}}{\text{interference power + background noise power}}.$$

Figure 1 shows the time-varying SINR of a user.

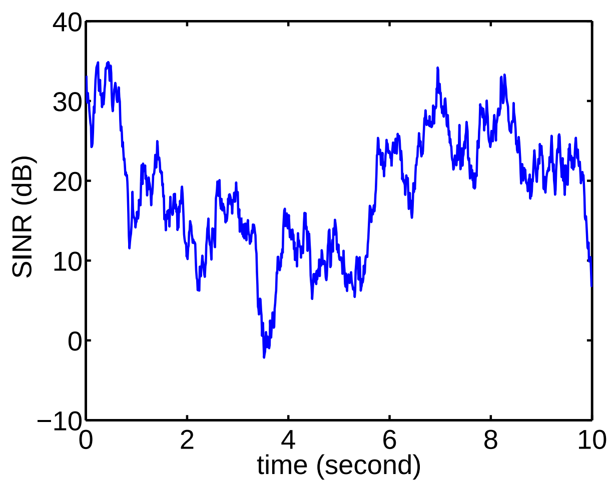

Figure 1: Time-varying SINR of a user.

Because channel conditions are time-varying and location-dependent, users experience time-varying and location-dependent service. For example, a better channel condition may result in a better voice quality for a voice service and a higher capacity of the channel. Theoretically, Shannon's capacity of the channel is formulated by

$$C = W \log_2(1 + SINR),$$

where C is data rate and W is bandwidth of the channel. Hence, even though the same amount of resource (e.g., power and time) is allocated to users, each user may experience different performance. This implies that different allocation of the wireless resource will affect the system performance. Intuitively, by giving a higher priority to users experiencing good channel conditions, we can improve the total system performance. However, this strategy may lead to unfairness and fail to satisfy QoS requirements of some users experiencing poor channel conditions. This is a basic dilemma in the wireless resource allocation problem. However, if we can appropriately exploit the time-varying channel condition of each user, this problem can be alleviated. As shown in Figure 2, each user experiences a different channel condition at a different time. Therefore, by scheduling users opportunistically taking into account fairness or QoS requirements of users such that a user can exploit more of its good channel conditions and avoid (as much as possible) bad times, we can achieve a high system efficiency and at the same time satisfy fairness or QoS requirements of users.

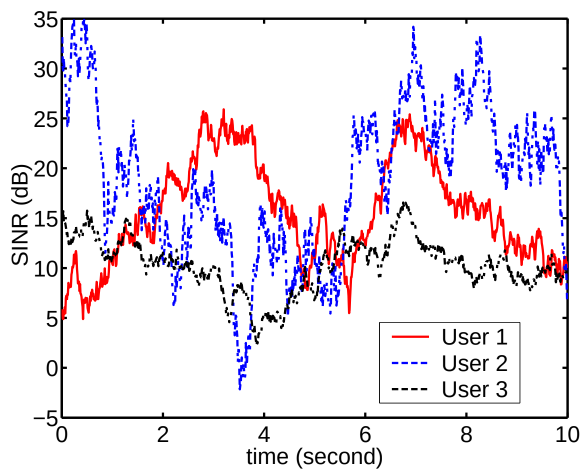

Figure 2: Time-varying SINRs of multiple users.

In this project, you will simulate and study various scheduling schemes in wireless systems, and compare their performance. After completing this project, you should understand:

- the impact of the channel condition of each user on its performance.
- the trade-off between efficiency and fairness in wireless systems.
- the importance of utilizing the time-varying channel condition of each user in wireless systems.

Problems

In this experiment, we study various scheduling schemes in the wireless system and compare their performance.

System model

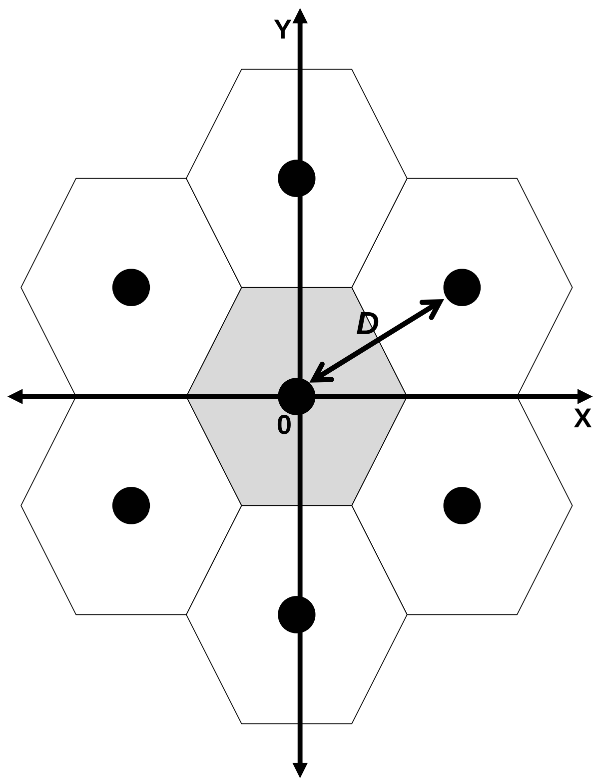

Figure 3: Cellular network model.

- Consider a cellular network in Figure 3.
  - A base-station is located at the center of each cell.
  - Distance between base-stations is D.
  - We will be interested in the center-cell and take the power from other cells as interference.
- The system is time-slotted.
- Each base-station transmits at the power level P_T.

- Focus on a downlink in the center cell of the network.
  - There are N users (from user 1 to user N) in the cell.
  - The base-station has infinite work load for each user.
- Path gain from base-station i to user j in time-slot n is modeled by

$$G_{i,j}^n = \frac{S_{i,j}^n}{(d_{i,j}^n)^\alpha}, \tag{2}$$

  where
  $S_{i,j}^n$: slow shadowing that is log-normally distributed with zero mean and a variance σ^2,
  $d_{i,j}^n$: distance between base-station i and user j, and
  α: distance loss exponent.
  - For the sake of simplicity of the project, let us assume that $S_{i,j}^n$ in (2) is independent and identically distributed in each time-slot n. Note that this assumption is good only when users move quickly in a circle centered at the base-station. A higher-fidelity model for path gain will involve more general mobility patterns and time-selective multipath fading.
  - We assume that $N_j^n = 0$.
- The SINR of user j in time-slot n that communicates with the base-station k, γ_j^n, is defined by

$$\gamma_j^n = \frac{G_{k,j}^n P_T}{\sum_{i \neq k} G_{i,j}^n P_T + N_j^n},$$

  where N_j^n is a background noise level at user j.
- The base-station has perfect knowledge about each user's channel condition (SINR).
- In time-slot n, the base-station selects only one user j^n and transmits a packet to it at a rate $R_{j^n}^n$, which is defined by Shannon's formula as

$$R_{j^n}^n = W \log_2(1 + \gamma_{j^n}^n),$$

  where W is the bandwidth of the system.
- Parameters for the system are summarized in Table 1. Here, we omit the unit for each parameter.

Table 1: Parameters for the System

W	P_T	α	σ (dB)	D	N
1	10	4	8	1000	4

Problem 1: Round-robin scheduling

- In each time-slot n, the base-station picks a user j^n for transmission in a round-robin fashion.

1. Devise a scheduling scheme.
2. Symmetric case
   - Generate four users in the center cell. Users 1, 2, 3, and 4 are located at coordinates (D/3,0), (0,D/3), (-D/3,0), and (0,-D/3), respectively.
   - Simulate round-robin scheduling for 10^4 time-slots.
   - Measure the fraction of time-slots that each user is scheduled, which is defined by
   $$\frac{\text{the number of time-slots in which the user is scheduled}}{\text{the total number of time-slots}}.$$
   - Measure the throughput of each user, which is defined by
   $$\frac{\text{the sum of data rate that is scheduled for the user in each time-slot}}{\text{the total number of time-slots}}$$
   and the total system throughput (i.e., the sum of all users' throughput).
3. Asymmetric case
   - Generate four users in the center cell. Users 1, 2, 3, and 4 are located at coordinates (D/5,0), (0,D/4), (-D/3,0), and (0,-D/2), respectively.
   - Repeat the procedures in the symmetric case.
4. Compare the results of the symmetric case and the asymmetric case, and discuss them.

Problem 2: Greedy scheduling

- In each time-slot n, the base-station picks a user j^n for transmission such that the expected total system throughput is maximized.

1. Devise the scheduling scheme that can achieve the above objective.
2. Simulate this scheme for both symmetric and asymmetric cases.
3. Compare the results of symmetric and asymmetric cases, and discuss them.
4. Compare the results with those of the round-robin scheme, and discuss them.

Problem 3: Opportunistic scheduling with temporal fairness

- In each time-slot n, the base-station picks a user j^n for transmission such that the expected total system throughput is maximized subject to the constraint that a minimum fraction of time-slots, r_i, must be assigned to user i.

1. Formulate the problem for an opportunistic scheduling policy with the above temporal fairness constraint.
2. What is the form of the optimal policy?
3. Devise a scheduling scheme to implement the optimal policy.
4. Simulate this scheme with $r_i = 1/4$, $\forall i$ for both symmetric and asymmetric cases.
5. Measure the fraction of time-slots that each user is scheduled, the throughput of each user, and the total system throughput.
6. Compare the results with those of round-robin and greedy schemes, and discuss them.
7. Simulate this scheme with $r_i = 1/8$, $\forall i$ for both symmetric and asymmetric cases.
8. Measure the average number of slots that each user is scheduled, the throughput of each user, and the total system throughput.
9. Compare the results of symmetric and asymmetric cases, and discuss them.
10. Compare the results of the cases with $r_i = 1/4$ and $r_i = 1/8$, and discuss them.

Deliverables

- Due date: February 21, 2020 in class.
- The report should contain answers to the problems, description of algorithms proposed, simulation results/figures, and any other comments and conclusions. A hard copy of the report should be turned-in in class. The source code of the project should be compressed into one single zipped file and emailed to the instructor by 2:30PM, February 21. (You do not need to print your source code.)

References

[1] X. Liu, E. K. P. Chong, and N. B. Shroff, "Opportunistic transmission scheduling with resource sharing constraints in wireless networks," *IEEE Journal of Selected Areas in Communications*, vol. 19, no. 10, pp. 2053-2065, Oct. 2001.
[2] X. Liu, E. K. P. Chong, and N. B. Shroff, "A framework for opportunistic scheduling in wireless networks," *Computer Networks*, vol. 41, no. 4, pp. 451-474, Mar. 2003.